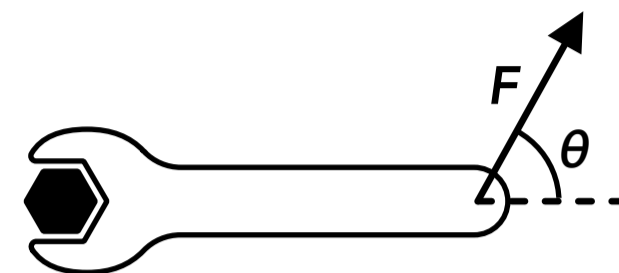


## Torque

- Which of the following is the SI unit for torque?
  - N
  - m
  - N·m
  - N/m
- By convention, a force generates a positive torque on an object if...
  - the force would rotate the object clockwise about its axis of rotation
  - the force would rotate the object counterclockwise about its axis of rotation
  - the force is in the positive  $x$  or  $y$  direction
  - the torque would cause the object to begin rotating or rotate faster
- In which of the following scenarios is a torque generated about a rotating axis? (Select all that apply)
  - A person pulling on a door handle to open a door
  - A person pushing on the middle of a block
  - A person using a screwdriver to tighten a screw
  - A block hanging from a rope
- A person is trying to turn a bolt with a wrench and they apply a force to a point on the handle, at an angle that is not perpendicular to the handle. Which of the following would increase the amount of torque applied to the bolt? (Select all that apply)
  - The force is applied closer to the bolt
  - The magnitude of the force is increased
  - The force is applied perpendicular to the handle
  - The force is applied farther from the bolt
- A person pushes perpendicularly on the surface of a door. Which of the following values would be needed to calculate the torque generated about the door hinge? (Select all that apply)
  - The magnitude of the applied force
  - The mass of the door
  - The width of the door
  - The distance between the door hinge and the point where the force is applied
- Which of the following is true if a torque is generated from a linear force?
  - The force must be perpendicular to the radial line
  - The force is not parallel to the radial line (not pointing directly at or away from the axis of rotation)
  - The force is great enough to cause the object to rotate
  - The force would cause the object to rotate counterclockwise

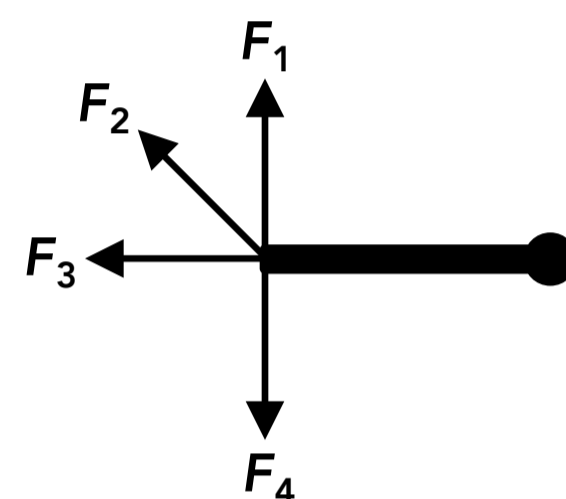
7. A person pulls on a door handle, perpendicular to the door. If the door handle was moved from the side of the door (opposite from the door hinge) to the center of the door and the same pulling force was applied, the magnitude of the torque applied to the door would...
- A increase
  - B stay the same
  - C decrease
  - D cannot be determined

8. A force is applied to the end of a wrench as shown on the right. If the angle  $\theta$  increases, the torque applied to the bolt on the left would...



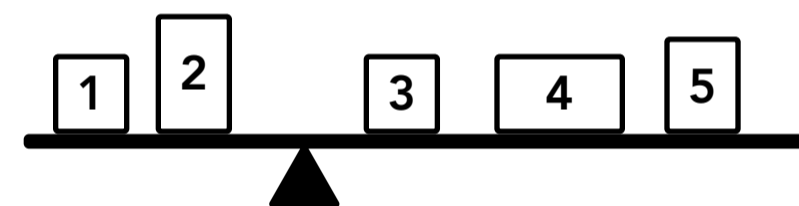
- A increase
- B stay the same
- C decrease
- D cannot be determined

9. Four forces of equal magnitude are applied to the left end of a rod which can rotate about its right end as shown on the right. Rank the magnitudes of the torques generated by each force.



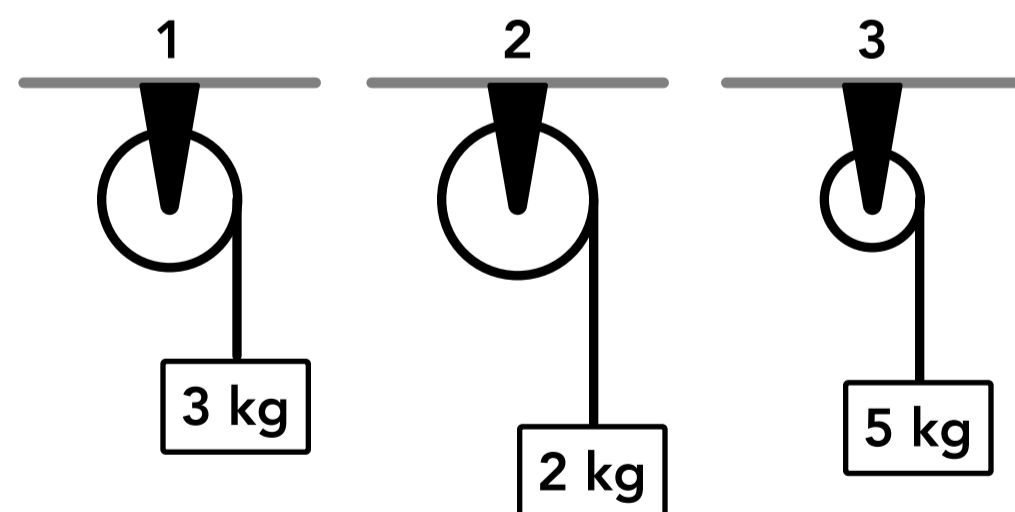
- A  $\tau_1 < \tau_3 < \tau_2 < \tau_4$
- B  $\tau_2 < \tau_1 = \tau_4 < \tau_3$
- C  $\tau_4 < \tau_3 < \tau_2 < \tau_1$
- D  $\tau_3 < \tau_2 < \tau_1 = \tau_4$

10. Several blocks are sitting on a beam which is balanced on a pivot point as shown on the right. The weight force from which blocks produce a positive torque about the pivot point?



- A Block 3, block 4, block 5
- B Block 1, block 2
- C Block 2, block 3
- D Block 1, block 5

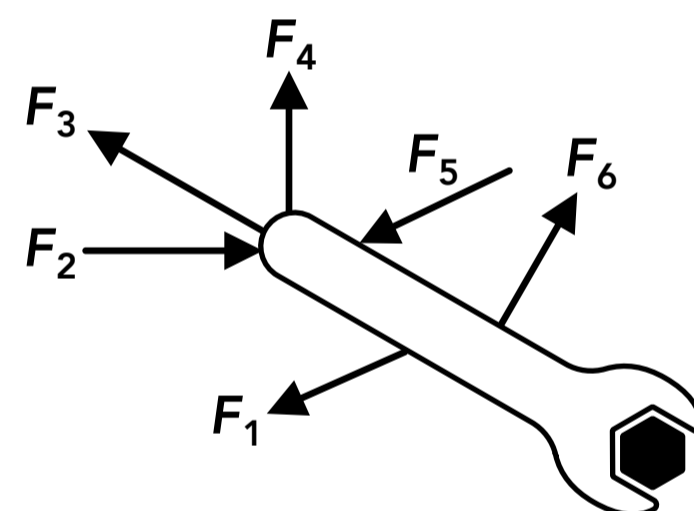
11. Three blocks are attached to three ropes which are wrapped around the outside of three pulleys as shown on the right. Pulley 1 has a radius of 6 cm, pulley 2 has a radius of 7 cm and pulley 3 has a radius of 3 cm. Rank the magnitudes of the torques produced about the center axis of each pulley.



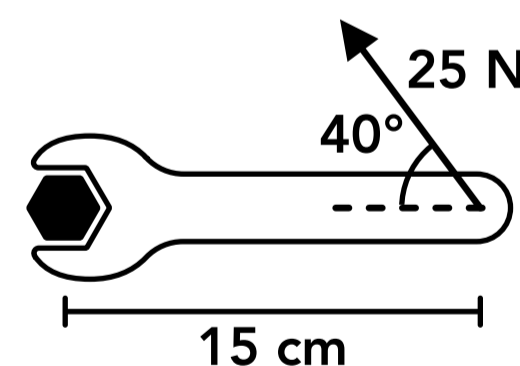
- A  $\tau_2 < \tau_1 < \tau_3$
- B  $\tau_3 < \tau_1 < \tau_2$
- C  $\tau_2 < \tau_3 < \tau_1$
- D  $\tau_1 < \tau_3 < \tau_3$

12. A 20 N force is applied to a rod at an angle of  $30^\circ$  to the rod, 2 m away from its axis of rotation. What is the torque produced by the force?
13. A person pushes on a door at an angle of  $70^\circ$  to the door at a point that is 50 cm from the door hinge, producing a torque of 50 N·m about the door hinge. What is the magnitude of the force applied by the person?
14. A force of 10 N is applied to the very end of a wrench, perpendicular to the wrench. If the force produces a torque of 2 N·m about the other end of the wrench, how long is the wrench?
15. A rope is attached to the end of a 2 m long pole which can pivot about the other end. If the tension in the rope is 10 N and the torque produced from the rope about the pivot is 6 N·m, what is the angle between the rope and the pole?

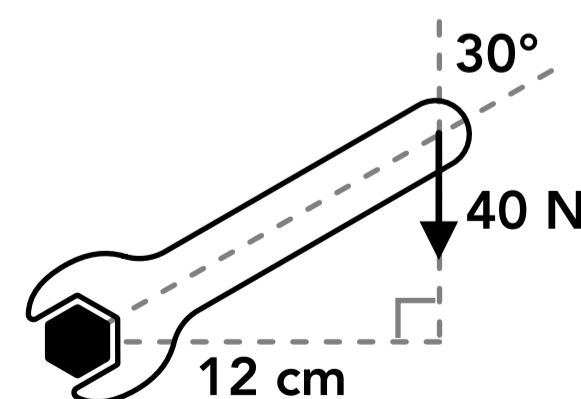
16. Multiple forces are exerted on a wrench as shown on the right. By convention, which forces produce a negative torque about the center of the bolt (lower right end of the wrench)?



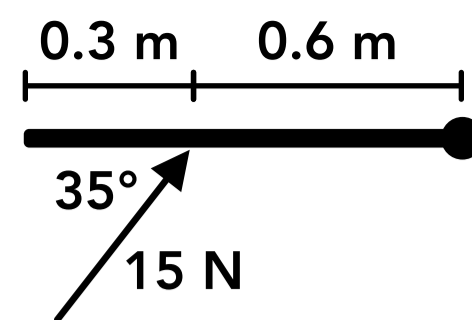
17. A force is applied to a wrench as shown on the right. What is the torque produced by the force, and is it positive or negative?



18. A force is applied to a wrench as shown on the right. What is the torque produced by the force, and is it positive or negative?



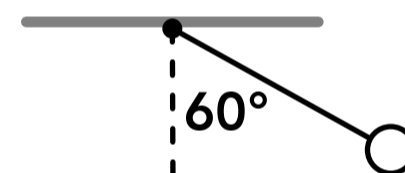
19. A force is exerted on a door as shown on the right, which rotates about its right end. What is the torque produced by the force, and is it positive or negative?



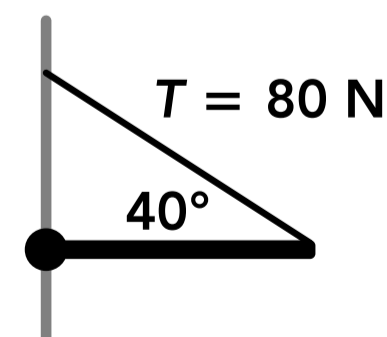
20. Two blocks are placed on a beam which is balanced on a pivot point as shown on the right. Block A has a mass of 16 kg and its center is 1.5 m away from the beam's pivot point. What is the magnitude of the torque on the beam caused by block A?



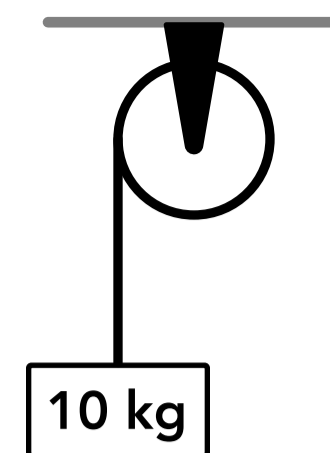
21. A pendulum consisting of a 5 kg ball and a 80 cm long rod of negligible mass is at the position in its swing as shown on the right. What is the magnitude of the torque on the pendulum's pivot point caused by the ball?



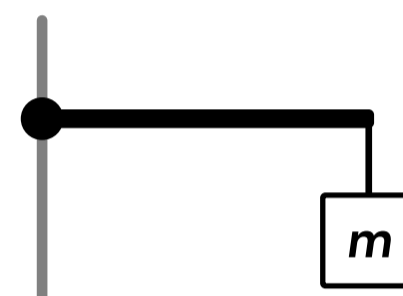
22. The left end of a pole is attached to a wall and the right end is supported by a rope which is also attached to the wall above the pole as shown on the right. The tension in the rope is 80 N. If the rope produces a torque of 20 N·m about the left end of the pole, what is the length of the pole?



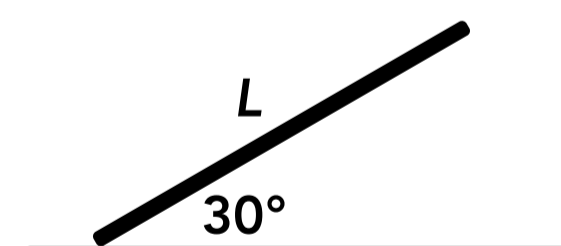
23. A block is attached to a rope which is wrapped around the outside of a pulley as shown on the right. If the diameter of the pulley is 30 cm, what is the magnitude of the torque produced by the block on the center of the pulley?



24. A block is hanging from a rope attached to the right end of a 60 cm long pole which is attached to a wall on the left end. If the block produces a 40 N·m torque about the left end of the pole, what is the mass of the block?



25. A 10 kg rod is touching the floor at its left end but is not supported anywhere else as shown on the right. Assume that the weight force on the rod acts at the center of the length of the rod. If the weight of the rod produces a torque of 50 N·m about its left end, what is the length of the rod,  $L$ ?



## Answers

- |            |       |             |                     |              |
|------------|-------|-------------|---------------------|--------------|
| 1. C       | 6. B  | 11. C       | 16. $F_2, F_4, F_6$ | 21. 33.9 N·m |
| 2. B       | 7. C  | 12. 20 N·m  | 17. 2.4 N·m         | 22. 0.39 m   |
| 3. A, C    | 8. A  | 13. 106.4 N | 18. -4.8 N·m        | 23. 14.7 N·m |
| 4. B, C, D | 9. D  | 14. 0.2 m   | 19. -4.3 N·m        | 24. 6.8 kg   |
| 5. A, D    | 10. B | 15. 17.5°   | 20. 235.2 N·m       | 25. 1.2 m    |

## Answers - Torque

1. **Answer: C**

The SI unit for torque is N·m, which can be found from the units in the equation for torque,  $\tau = rF_{\perp}$ .

2. **Answer: B**

Conventionally, counterclockwise is the positive rotational direction. A force that would cause an object to rotate counterclockwise generates a positive torque, and a force that would cause an object to rotate clockwise generates a negative torque.

3. **Answer: A, C**

When a person pulls on a door handle to open a door, a pulling force is exerted on the door (likely perpendicular to the door) some distance from the axis of rotation (the door hinge) which generates a torque on the door. When a person turns a screwdriver, a friction force is exerted on the outer surface of the handle (a force acting at every point of contact between their hand and the handle which acts tangential to the surface of the handle) which is at a distance from the axis of rotation (the radius of the handle) which generates a torque. When a person pushes on the middle of a block or a block is hanging from a rope, the forces act directly towards or away from the axis of rotation so no torque is generated.

4. **Answer: B, C, D**

The magnitude of the torque applied to the bolt is equal to the distance between the axis of rotation (the center of the bolt) and the point where the force is applied, times the magnitude of the component of the force that is perpendicular to the handle (the radial line),  $\tau = rF_{\perp}$ . The torque would increase if the magnitude of the force increased, the distance between the force and the bolt increased, or if the force acts perpendicular to the handle instead of at another angle (so that the perpendicular component of the force is maximized).

5. **Answer: A, D**

The magnitude of the torque about the door hinge (the axis of rotation) is equal to the distance between the door hinge and the point where the force is applied, times the magnitude of the component of the force that is perpendicular to the door (the radial line),  $\tau = rF_{\perp}$ . Since we know the force is perpendicular to the door, we need to know the magnitude of the force and the distance between the door hinge and the point where the force is applied, not the width of the door.

6. **Answer: B**

A torque is generated about an axis of rotation from a linear force if some component of the force is perpendicular to the radial line (not parallel to the radial line). The entire force vector does not have to be perpendicular, only a component of it.

7. **Answer: C**

The magnitude of the torque on the door is equal to the distance between the door hinge and the handle (the point where the force is applied) times the magnitude of the pulling force (which is perpendicular),  $\tau = rF_{\perp}$ . If the handle was moved to the center of the door, the distance between the door hinge and the point where the force is applied would decrease, so the magnitude of the torque would decrease.

8. **Answer: A**

The torque applied to the bolt is proportional to the component of the force that is perpendicular to the wrench handle (radial line). If the angle increases, the perpendicular component of the force also increases (it would be at its maximum when the angle is  $90^\circ$  and the force is completely perpendicular).

9. **Answer: D**

The forces have the same magnitude and act at the same point (so the same distance from the axis of rotation) so a force will generate a greater torque if its component which is perpendicular to the rod is greater. The torques generated from forces 1 and 4 are the greatest since they are perpendicular to the rod, and the torques are equal. The torque generated from force 2 is less than torques 1 and 4 since force 2 is not fully perpendicular to the rod. Force 3 generates zero torque because it is not perpendicular to the rod, it is parallel to the radial line and acts directly away from the axis of rotation. Since we are ranking the magnitudes of the torques the positive and negative directions are not relevant.

10. **Answer: B**

By convention, counterclockwise torques are positive (forces that would rotate the beam counterclockwise about the pivot point produce positive torques). The weight forces from block 1 and block 2 produce counterclockwise torques (positive) and the weight forces from blocks 3, 4 and 5 produce clockwise torques (negative).

11. **Answer: C**

The section of the rope hanging from each pulley exerts a tension force on the outer edge of the pulley which acts perpendicular to the radial line (a line between the center axis of the pulley and the point where the force is applied, the right side of each pulley). The tension force exerted on each pulley is equal in magnitude to the weight of each block. The magnitude of the torque produced about the center axis of each pulley is:

$$\text{Pulley 1: } \tau = rF_{\perp} = (0.06 \text{ m})(3 \text{ kg})g = 1.76 \text{ N}\cdot\text{m}$$

$$\text{Pulley 2: } \tau = rF_{\perp} = (0.07 \text{ m})(2 \text{ kg})g = 1.37 \text{ N}\cdot\text{m}$$

$$\text{Pulley 3: } \tau = rF_{\perp} = (0.03 \text{ m})(5 \text{ kg})g = 1.47 \text{ N}\cdot\text{m}$$

12. **Answer: 20 N·m**

$$\tau = rF_{\perp} = (2 \text{ m})(20 \text{ N})\sin(30^\circ) = 20 \text{ N}\cdot\text{m}$$

13. **Answer: 106.4 N**

$$\tau = rF_{\perp} \quad (50 \text{ N}\cdot\text{m}) = (0.5 \text{ m})F\sin(70^\circ) \quad F = 106.4 \text{ N}$$

14. **Answer: 0.2 m**

$$\tau = rF_{\perp} \quad (2 \text{ N}\cdot\text{m}) = r(10 \text{ N}) \quad r = 0.2 \text{ m}$$

15. **Answer: 17.5°**

$$\tau = rF_{\perp} \quad (6 \text{ N}\cdot\text{m}) = (2 \text{ m})(10 \text{ N})\sin(\theta) \quad \theta = 17.5^\circ$$

16. **Answer:  $F_2, F_4, F_6$**

By convention, clockwise torques are negative (forces that would rotate the wrench clockwise produce negative torques).  $F_3$  produces zero torque and the other forces produce positive (counterclockwise) torques.

17. **Answer: 2.4 N·m**

$$\tau = rF_{\perp} = (0.15 \text{ m})(25 \text{ N})\sin(40^\circ) = 2.4 \text{ N}\cdot\text{m}$$

The torque is counterclockwise so it's positive.

18. **Answer: -4.8 N·m**

One way to calculate the torque produced by a force is to multiply the distance between the axis of rotation (the center of the bolt) and the line of force (a line passing through the force vector) times the full magnitude of the force,  $\tau = r_{\perp} F$ . The given angle is not needed because the distance between the axis of rotation and the line of force (12 cm) is given.

$$\tau = r_{\perp} F = (0.12 \text{ m})(40 \text{ N}) = 4.8 \text{ N}\cdot\text{m}$$

The torque is clockwise so it's negative.

19. **Answer: -4.3 N·m**

$$\tau = rF_{\perp} = (0.6 \text{ m})(15 \text{ N})\sin(35^{\circ}) = 4.3 \text{ N}\cdot\text{m}$$

The torque is clockwise so it's negative.

20. **Answer: 235.2 N·m**

The torque is produced by the weight force of the block which acts perpendicular to the beam.

$$\tau = rF_{\perp} = (1.5 \text{ m})(16 \text{ kg})g = 235.2 \text{ N}\cdot\text{m}$$

21. **Answer: 33.9 N·m**

The torque on the pivot point is produced by the weight force of the ball. Using geometry, the angle between the vertical weight force vector and the radial line (a line parallel to the rod) is  $60^{\circ}$ .

$$\tau = rF_{\perp} = (0.8 \text{ m})(5 \text{ kg})g\sin(60^{\circ}) = 33.9 \text{ N}\cdot\text{m}$$

22. **Answer: 0.39 m**

$$\tau = rF_{\perp} \quad (20 \text{ N}\cdot\text{m}) = r(80 \text{ N})\sin(40^{\circ}) \quad r = 0.39 \text{ m}$$

23. **Answer: 14.7 N·m**

The section of the rope hanging from the pulley exerts a tension force on the outer edge of the pulley which acts perpendicular to the radial line (a line between the center axis of the pulley and the point where the force is applied, the left side of the pulley). The tension force exerted on the pulley is equal in magnitude to the weight of the block.

$$r = d/2 = (30 \text{ cm})/2 = 15 \text{ cm}$$

$$\tau = rF_{\perp} = (0.15 \text{ m})(10 \text{ kg})g = 14.7 \text{ N}\cdot\text{m}$$

24. **Answer: 6.8 kg**

The torque on the left end of the pole is produced by the weight force of the block (the tension force from the rope, which is equal in magnitude to the weight of the block).

$$\tau = rF_{\perp} \quad (40 \text{ N}\cdot\text{m}) = (0.6 \text{ m})mg \quad m = 6.8 \text{ kg}$$

25. **Answer: 1.2 m**

The force producing the torque is the weight force acting at the center of the rod, so the distance between the point where the force is acting on the rod and the axis of rotation (the left end) is half of the length of the rod. Using geometry, the angle between the weight force and the radial line (a line parallel to the rod) is  $60^{\circ}$ .

$$\tau = rF_{\perp} \quad (50 \text{ N}\cdot\text{m}) = \frac{L}{2}(10 \text{ kg})g\sin(60^{\circ}) \quad L = 1.2 \text{ m}$$